Reductions in dietary energy density are associated with weight loss in overweight and obese participants in the PREMIER trial[1–4]

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ABSTRACT

Background: Dietary energy density (ED) reductions are associated with energy intake (EI) reductions. Little is known about influences on body weight (BW).

Objectives: We examined the effects of behavioral interventions on ED values and explored how 6-mo ED changes relate to BW.

Design: Prehypertensive and hypertensive persons were randomly assigned to 1 of 3 groups: the established group received an 18-session intervention implementing well-established hypertension recommendations (eg, weight loss, sodium reduction, and physical activity), the established+Dietary Approaches to Stop Hypertension (DASH) group received an 18-session intervention also implementing the DASH diet, and the advice group received 1 session on these topics. Two 24-h dietary recalls were collected ($n = 658$).

Results: Each group had significant declines in EI, ED, and BW. The established and established+DASH groups had the greatest EI and BW reductions. The established+DASH group had the greatest ED reduction and the greatest increase in the weight of food consumed. When groups were combined and analyzed by ED change tertiles, participants in the highest tertile (ie, largest ED reduction) lost more weight (5.9 kg) than did those in the middle (4.0 kg) or lowest (2.4 kg) tertile. Participants in the highest and middle tertiles increased the weight of food they consumed (300 and 80 g/d, respectively) but decreased their EI (500 and 250 kcal/d). Conversely, those in the lowest tertile decreased the weight of food consumed (100 g/d), with little change in EI. The highest and middle tertiles had favorable changes in fruit, vegetable, vitamin, and mineral intakes.

Conclusion: Both large and modest ED reductions were associated with weight loss and improved diet quality. *Am J Clin Nutr* 2007;85:1212–21.

KEY WORDS Energy density, obesity, weight management, food patterns, fruit and vegetables, PREMIER trial, Dietary Approaches to Stop Hypertension, DASH

INTRODUCTION

Consumption of foods that are low in energy density (kcal/g) has been suggested by *Dietary Guidelines for Americans 2005* (1) as a strategy for reducing energy intake (EI). Multiple short-term, laboratory-based studies found that persons consume less energy when presented with lower-energy-density foods than with similar foods having a greater energy density (2–8). Lower EIs have also been associated with lower-energy-density diets in cross-sectional studies (9–12). Whereas data from cross-sectional studies suggest that diets with lower energy density are associated with healthier body weights (11–14), few longitudinal studies have examined relations between changes in dietary energy density and weight loss. Prospective studies reported to date suggest that weight loss for overweight and obese persons can be increased by providing lower-energy-density snacks as part of an energy-restricted diet (15) or by providing counseling to increase fruit and vegetable intakes as part of a reduced-fat diet (16). There is a need for further studies of the influence of dietary interventions on changes in the energy density of the diet and the ways in which these changes are related to weight loss.

Dietary energy density is mainly influenced by the consumption of fruit, vegetables, and fat (17). Fruit and vegetables, which have relatively high water content, decrease the energy density of the diet, because water adds weight but not energy to foods. Dietary energy density can also be reduced by consuming less fat, because fat has a higher energy density (9 kcal/g) than does either carbohydrate or protein (4 kcal/g). The PREMIER clinical trial provides an opportunity to explore relations between reductions in dietary energy density and weight loss. This large, multicenter clinical trial tested several dietary interventions, one of which included the Dietary Approaches to Stop Hypertension (DASH) diet, as part of a comprehensive behavioral intervention to reduce blood

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pressure. The DASH diet recommends increased consumption of fruit and vegetables (9–12 servings/d) and low-fat diary products (2–3 servings/d) and a reduced intake of fat (<25% of energy) (18). Whereas the DASH diet has been recognized as a healthful eating pattern by government organizations (1), information regarding how the adoption of this eating plan influences energy density is not available.

Given the rising prevalence of obesity (19), there is an urgent need for effective weight-management strategies. Reductions in the energy density of the diet may be an effective weight-loss strategy that helps persons maintain diet quality (14, 20). Therefore, the current study examined the effect of the dietary interventions used in the PREMIER trial on dietary energy density and investigated whether changes in dietary energy density values over a period of 6 mo were related to changes in anthropometric, dietary, and health-related measures.

SUBJECTS AND METHODS

Details of the PREMIER study design and interventions were published elsewhere (21, 22), as were the main results of the study (23). In brief, this trial investigated the effects of 3 nonpharmacologic interventions designed to reduce blood pressure. Participating institutions included the National Heart, Lung, and Blood Institute Project Office (Bethesda, MD), the Coordinating Center (Kaiser Permanente Center for Health Research, Portland, OR), and 4 clinical centers (Duke University Medical Center, Durham, NC; Johns Hopkins University, Baltimore, MD; Pennington Biomedical Research Center, Baton Rouge, LA; and Kaiser Permanente Center for Health Research, Portland, OR).

Each participant provided written informed consent. The institutional review board at each center and an external protocol review committee approved the trial protocol.

Study participants

The target population consisted of generally healthy adults with above-normal blood pressure. Inclusion criteria correspond to prehypertension and stage 1 hypertension guidelines set in the 7th report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (JNC-7; 24), which were established after the study was completed. Specifically, persons were eligible if they had a systolic blood pressure of 120 to 159 mm Hg, a diastolic blood pressure of 80 to 95 mm Hg, or both, as determined from the mean blood pressure across 3 screening visits, and if they were not taking antihypertensive medication. Other inclusion criteria included age ≥25 y and a body mass index (BMI; in kg/m^2) of 18.5 to 45.0. Major exclusion criteria were regular use of drugs that affect blood pressure, JNC-7 risk category C (target organ damage, diabetes, or both), use of weight-loss medications, prior cardiovascular event, heart failure, angina, cancer diagnosis or treatment in the past 2 y, consumption of > 21 alcoholic drinks/wk, pregnancy, planned pregnancy, or lactation. Targeted recruitment methods were used to ensure adequate representation of clinically important subgroups, such as African Americans.

A total of 810 participants were enrolled in the trial. The analyses presented here are based on overweight and obese subjects with dietary and anthropometric data at baseline and 6 mo. Three participants who reported consuming <500 kcal/d at either baseline or 6 mo were excluded from the analyses, which left 658 subjects, or 81% of the randomly assigned subjects. The percentage of randomly assigned subjects excluded from these analyses did not differ significantly by PREMIER treatment group.

Interventions

After eligibility was established, study participants were randomly assigned to 1 of 3 groups: the advice group, the established group, and the established+DASH group (21, 22). Those assigned to the advice group received a single 30-min individual educational session at the time of randomization. During that session, participants received oral information and written materials on nonpharmacologic factors affecting blood pressure (eg, weight, sodium intake, physical activity, and the DASH diet). In contrast, participants assigned to either the established or the established+DASH group were scheduled to attend 18 face-to-face intervention contacts over 6 mo (14 group meetings and 4 individual counseling sessions). Participant goals for both of these intensive behavioral interventions were weight loss of ≥6.8 kg (15 lb) at 6 mo for those with a BMI ≥ 25, ≥180 min/wk of moderate-intensity physical activity, ≤100 mmol dietary sodium/d, and ≤30 mL alcohol/d (1 oz/d; 2 drinks) for men and 15 mL alcohol/d (0.5 oz/d; 1 drink) for women. Participants in both groups received similar goals for EI restrictions. In addition, participants in the established+DASH intervention were counseled to consume the DASH dietary pattern, with the following goals: 9–12 daily servings of fruit and vegetables, 2–3 daily servings of low-fat dairy products, and total fat and saturated fat intakes of ≤25% and ≤7% of total calories, respectively (18). For the established group, goals for fruit, vegetable, and low-fat diary intake were not specified. Their dietary advice included reductions in total EI with ≤30% of energy coming from fat and ≤10% coming from saturated fat. The intervention lasted a total of 18 mo; this report includes the first 6 mo after randomization, designated during study design as the period of primary outcome analysis.

Measurements

All measurements were obtained at baseline and 6 mo after randomization by staff members who were unaware of randomization assignment. Intake of energy, nutrients, and food groups was assessed from 2 unannounced, nonconsecutive 24-h dietary recalls collected by telephone on one weekend and one weekday. Recalls were administered by the Diet Assessment Center of The Pennsylvania State University with the use of NUTRITION DATA SYSTEM software (version NDS-R 1998; University of Minnesota, Minnesota, MN). Dietary data for each day were collected by using a multiple-pass technique and portion size estimation aids to improve the quality of the data collected. Energy density values were calculated only on the basis of food intake, excluding all beverages (25). Prior research indicated that including beverages in calculations of dietary energy density values may diminish associations with outcome variables because of increased within-person variance (25). Weight, height, and waist circumference were measured by using calibrated scales, wall-mounted stadiometers, and anthropometric measuring tape, respectively. A 7-d physical activity recall was used to assess physical activity (26).

Statistical analysis

The data were analyzed with SAS software (version 9.1; SAS Institute Inc, Cary, NC). Analyses were conducted to compare

TABLE 1
Change in anthropometric measures and diet-related variables in 6 mo by PREMIER trial treatment group[1]

	Advice group (n = 223)	Established group (n = 219)	Established+DASH group (n = 216)
Body weight (kg)			
Baseline	96.1 ± 1.1	96.0 ± 1.2	99.1 ± 1.3
Change[2]	−1.1 ± 0.2[a]	−5.1 ± 0.4[b]	−6.1 ± 0.4[b]
Waist circumference (cm)			
Baseline	108.6 ± 0.9	108.5 ± 0.9	110.5 ± 1.0
Change[2]	−1.3 ± 0.4[a]	−5.3 ± 0.4[b]	−5.3 ± 0.4[b]
BMI (kg/m^2)			
Baseline	33.4 ± 0.3	33.5 ± 0.3	33.9 ± 0.4
Change[2]	−0.5 ± 0.1[a]	−1.8 ± 0.1[b]	−2.2 ± 0.1[b]
Energy density (kcal/g food)[3]			
Baseline	1.76 ± 0.03	1.80 ± 0.03	1.78 ± 0.03
Change[2]	−0.17 ± 0.03[a]	−0.26 ± 0.04[a]	−0.56 ± 0.03[b]
Total energy (kcal)			
Baseline	1941 ± 42	1949 ± 41	2013 ± 45
Change[2]	−173 ± 43[a]	−321 ± 37[b]	−286 ± 40[b]
Food energy (kcal)			
Baseline	1688 ± 38	1708 ± 37	1763 ± 42
Change[2]	−137 ± 40[a]	−257 ± 35[b]	−263 ± 38[b]
Beverage energy (kcal)			
Baseline	254 ± 13	241 ± 12	250 ± 12
Change[4]	−36 ± 13[a]	−64 ± 12[b]	−24 ± 14[a]
Food weight (g)			
Baseline	1001 ± 23	1003 ± 21	1051 ± 25
Change[5]	20 ± 24[a]	8 ± 20[a]	254 ± 27[b]

[1] All values are $\bar{x}$ ± SE. DASH, Dietary Approaches to Stop Hypertension. Values in the same row with different superscript letters are significantly different, $P < 0.05$ (ANOVA using a general linear model adjustment for baseline values and Tukey-Kramer adjustment for multiple comparisons). Baseline values did not differ significantly by treatment group. Paired t tests were used to determine whether change values differed from zero change.
[2] For each treatment group, the change value is significantly different from zero change.
[3] Energy density is based on food intake, excluding all beverages. Energy intake is presented as total reported intake of energy from all food and beverages. Energy intakes from foods and beverages are also reported separately. The weight of food consumed (food weight) is reported, but the total weight of food and beverages consumed is not reported, nor is the weight of beverages consumed, because the intake of noncaloric beverages was not assessed.
[4] For the advice group and the established group, the change value is significantly different from zero change.
[5] For the established+DASH group, the change value is significantly different from zero change.

participants by PREMIER treatment group. Comparisons were also made after classifying participants on the basis of the magnitude of change observed in dietary energy density values over a period of 6 mo by using tertile cutoffs. Chi-square tests and analysis of variance (ANOVA) were used for categorical and continuous independent variables, respectively. Baseline measures of independent variables were included as covariates. Post hoc tests using a Tukey-Kramer adjustment for multiple comparisons were conducted only after establishing that the overall F statistic for the ANOVA model was significant at $P < 0.05$. In addition, stepwise regression analyses were performed to determine which dietary changes were most predictive of changes in energy density and body weight.

RESULTS

Differences by PREMIER treatment group

Baseline characteristics did not differ significantly between the randomly assigned treatment groups (23). There were no significant differences between the participants according to group assignment for age, anthropometric measures, sex, race, education level, or income. Participants had a mean ± SE age of 50 ± 0.3 y and a mean BMI of 33.6 ± 0.2. Sixty-one percent of the participants in these analyses were women, 35% were African American, and 57% had a college degree. Initial dietary energy density values also did not differ significantly by treatment group: participants had a mean dietary energy density of 1.78 ± 0.02 kcal/g at baseline.

After 6 mo, mean body weight decreased significantly in all 3 treatment groups ($P < 0.001$). The magnitude of this change was greater, however, in the established+DASH (6.1 kg) and established (5.1 kg) groups than in the advice group (1.1 kg) (**Table 1**). A similar pattern was exhibited for changes in waist circumference and BMI. Reported energy intakes also declined for each of the 3 treatment groups ($P < 0.001$), with greater declines in the established and established+DASH groups than in the advice group.

Even though mean body weight and reported EI decreased in each treatment group, the total weight of food reported increased significantly, by >250 g, for those in the established+DASH group ($P < 0.001$), whereas there was no significant change in the weight of food reported by those in the advice and established groups. The increase in overall food intake by the established+DASH group was accompanied by the largest increases in fruit, vegetable, and dairy intakes (data not shown) (23). The established+DASH group and the established group

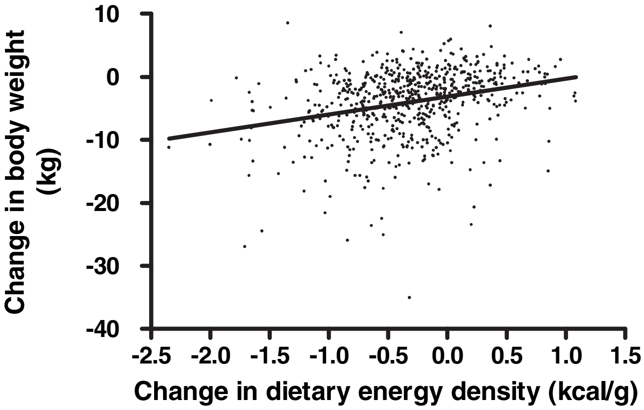

FIGURE 1. Pearson correlation between 6-mo changes in dietary energy density values and weight loss in all PREMIER trial participants (n = 658). Participants in each of the PREMIER treatment groups were combined for the analysis. Weight loss in all subjects combined at 6 mo was significantly correlated with the decrease in food energy density (r = 0.28, P < 0.001).

had the largest mean decreases in intakes of meat, fats and oils, and sweets (23).

There was also a significant (P < 0.001) decline in mean dietary energy density values in each of the 3 treatment groups: declines of 0.17 kcal/g in the advice group, 0.26 kcal/g in the established group, and 0.56 kcal/g in the established+DASH group. There was, however, considerable variability within each of the treatment groups. Approximately 22% of the participants in the advice group had an increase of ≥0.20 kcal/g in the energy density of their diet, compared with 16% of those in the established group and only 6% of those in the established+DASH group. Conversely, a decrease of ≥0.20 kcal/g in energy density values occurred in 47% of those in the advice group, 55% of those in the established group, and 76% of those in the established+DASH group. A more substantial decrease of ≥1.00 kcal/g was seen in 4% of the advice group, 6% of the established group, and 18% of the established+DASH group.

The extent to which EI was reduced did not differ significantly between the established+DASH and established groups. The amount of weight lost also did not differ between these 2 groups. The established+DASH group did, however, report consuming a diet that was significantly lower in energy density than did the established group. Consequently, the established+DASH group increased the total weight of food they consumed while reducing energy intakes. The reductions in EI and body weight experienced by the established group were not accompanied by an increase in the weight of food consumed.

Differences by change in dietary energy density values

Given that substantial changes in energy density were made by participants in each of the PREMIER treatment groups, analyses were conducted with the 3 groups combined. Weight loss for all participants at 6 mo was significantly correlated with lower food energy density (r = 0.28, P < 0.001; **Figure 1**). To examine more closely the relations between changes in dietary energy density values and changes in body weight and diet-related variables, participants were classified into tertiles on the basis of 6-mo energy density changes. When the tertile cutoffs were applied, participants with an increase or a relatively minor decrease (≤0.10 kcal/g) in the energy density of their diet were categorized together in tertile 1. Participants with a decline of 0.11 to 0.51 kcal/g were classified into tertile 2. These persons were considered to have a medium or modest decrease in the energy density of their diet. The remaining participants, those in tertile 3, had the largest decreases in dietary energy density—≥0.52 kcal/g.

Baseline characteristics by tertile of dietary energy density change are shown in **Table 2**. Mean age, energy expenditure, and anthropometric measures did not differ by tertile. Although there were no differences by sex, race, level of education, or income, the percentage of subjects from each PREMIER treatment group was not evenly balanced across the 3 energy density change categories. Half of the subjects classified as having a large decrease in energy density (tertile 3) received the established+DASH treatment, compared with 33% of those in tertile 2 and 15% of those in tertile 1.

The anthropometric and dietary profile of study participants categorized by the 6-mo change in dietary energy density values is shown in **Table 3**. Participants with a large decrease in the energy density of their diet (tertile 3) had a mean weight loss of 5.9 kg, which was significantly greater than the mean weight loss observed in subjects with a medium decrease in energy density (tertile 2; 4.0 kg) or an increase or small decrease in the energy density of their diet (tertile 1; 2.4 kg). The largest decrease in waist circumference and BMI was also observed in those in tertile 3.

Participants in tertile 3 had the greatest change in reported EI, which corresponded with the anthropometric changes. Mean EI for these participants decreased by ≈500 kcal/d. Those in tertile 2 had a decrease in EI of ≈280 kcal/d, whereas there was little change in the mean EI of those in tertile 1. Even though participants with a large decrease in the energy density of their diet (tertile 3) had a substantial decrease in EI, the mean weight of food they reported consuming increased by ≈300 g/d. Participants with a medium decrease in the energy density of their diet (tertile 2) had a more modest mean increase in reported food intake of 70 g/d. Conversely, for the remaining participants (tertile 1), there was a mean decrease of nearly 90 g/d.

Patterns of food intake differed among the 3 tertiles of energy density change. Participants with a large decrease in the energy density of their diet (tertile 3) had the greatest increases in both fruit (1.84 servings/d) and vegetable (1.24 servings/d) intakes, whereas those with a medium decrease in energy density (tertile 2) had more modest increases in fruit (0.97 servings/d) and vegetable (0.35 servings/d) intakes. Intakes of meats and sweets declined the most for those in tertiles 2 and 3, whereas the decrease in fat and oil consumption (as a food group) did not differ between the 3 tertiles.

These differences in reported food group intakes were accompanied by differences in nutrient intake profiles. Participants with a large decrease in the energy density of their diet (tertile 3) had the greatest decrease in fat and saturated fat intakes (as nutrients) and the greatest increase in fiber intake; those with a medium decrease in energy density (tertile 2) had the next greatest decline and increase, respectively. Moisture from foods consumed also increased for those in tertile 3. Participants in tertile 3 had increased intakes of many vitamins and minerals, whereas there was little change for participants in tertile 1. Specifically, intakes of vitamin A, vitamin B-6, vitamin C, and potassium increased most substantially among those with a large or medium decrease in energy density.

There was a significant mean decline in blood pressure in participants in each tertile. Those in tertile 3 had a slightly but

TABLE 2
Baseline characteristics of PREMIER trial participants categorized by tertile of 6-mo change in dietary energy density values[1]

	6-mo change in dietary energy density		
	Tertile 1 (increase or small decrease) (*n* = 219)	Tertile 2 (medium decrease) (*n* = 220)	Tertile 3 (large decrease) (*n* = 219)
Age (y)[2]	50.5 ± 0.6[3]	50.4 ± 0.6	49.0 ± 0.6
Body weight (kg)[2]	97.4 ± 1.2	95.5 ± 1.2	98.4 ± 1.2
Waist circumference (cm)[2]	109.1 ± 1.0	107.7 ± 1.0	110.8 ± 1.0
BMI (kg/m^2)[2]	33.5 ± 0.4	33.0 ± 0.4	34.3 ± 0.4
Energy expenditure (kcal · kg^{-1} · d^{-1})[2]	33.9 ± 0.2	33.8 ± 0.2	33.8 ± 0.2
Sex [*n* (%)][4]			
Male	83 (38)	92 (42)	80 (37)
Female	136 (62)	127 (58)	139 (63)
Race [*n* (%)][4]			
White	142 (65)	141 (64)	135 (62)
African American	71 (32)	78 (35)	82 (37)
Other	6 (3)	1 (1)	2 (1)
Education [*n* (%)][4]			
High school or less	18 (8)	24 (11)	15 (7)
Some college	72 (33)	69 (31)	84 (38)
College graduate	63 (29)	55 (25)	52 (24)
Some graduate school	66 (30)	72 (33)	68 (31)
Annual income [*n* (%)][4]			
<$29 999	20 (9)	19 (9)	27 (12)
$30 000–$59 000	71 (28)	75 (34)	62 (28)
$60 000–$89 000	80 (37)	67 (30)	72 (33)
≥$90 000	43 (20)	45 (20)	51 (23)
No response	5 (2)	14 (6)	7 (3)
Treatment group [*n* (%)][4]			
Advice	105 (48)	67 (30)	51 (23)
Established	80 (36)	80 (37)	59 (27)
Established+DASH	34 (15)	73 (33)	109 (50)

[1] DASH, Dietary Approaches to Stop Hypertension. The changes in energy density were 1.09 to −0.10, −0.11 to −0.51, and −0.52 to −2.35 kcal/g for increase or small decrease, medium decrease, and large decrease, respectively.
[2] ANOVA using a general linear model followed by a Tukey-Kramer adjustment for multiple comparisons was used for continuous variables. There were no significant differences.
[3] $\bar{x}$ ± SE (all such values).
[4] Chi-square analyses were performed on categorical variables. The only significant difference ($P < 0.05$) was by treatment group. The percentage of subjects from each PREMIER treatment group was not evenly balanced across the 3 categories of change in energy density.

significantly greater decrease in systolic blood pressure than did those in tertile 1.

Predicting changes in energy density and body weight

To investigate which dietary changes were most predictive of changes in dietary energy density, stepwise regression analyses were performed. We analyzed an initial model that included terms for macronutrient, fiber, moisture from food, and food group intakes; a second model also included baseline energy density values (**Table 4**). When baseline energy density values were excluded from the model, the strongest predictors of energy density changes were changes in fat (34%), vegetable (13%), and fruit (6%) intakes, which together accounted for most (53%) of the variance in the 6-mo energy density change. When included in the model, baseline energy density had a strong influence on energy density values at 6 mo, accounting for 37% of the variance in energy density change. This was followed by changes in fat, vegetable, and fruit intakes, which together accounted for an additional 29% of the variability.

A similar analysis was conducted to determine which diet-related variables were most predictive of weight loss. In addition to changes in macronutrient, fiber, moisture from food, and food group intakes, this analysis included terms for changes in energy density, EI, food weight, and physical activity. Regardless of whether baseline body weight was included in the model, the strongest predictor of weight loss was the decrease in food energy density, which accounted for 7% of the variability in weight loss. The next strongest predictors were changes in fiber intake, fat intake, and the weight of food consumed. These variables accounted for an additional 8% of the variance in weight loss.

DISCUSSION

Data from this large, multicenter study were used to examine diet patterns characterized by change in dietary energy values. These data indicate that weight loss over 6 mo was related to the change in the energy density of the diet. PREMIER trial participants with dietary patterns characterized by the greatest declines

TABLE 3
Change in anthropometric measures, diet-related variables, and blood pressure of PREMIER trial participants categorized by tertile of 6-mo change in dietary energy density values[1]

	6-mo change in dietary energy density		
	Tertile 1 (increase or small decrease) ($n = 219$)	Tertile 2 (medium decrease) ($n = 220$)	Tertile 3 (large decrease) ($n = 219$)
Weight change (kg)[2]	−2.4 ± 0.3[a]	−4.0 ± 0.3[b]	−5.9 ± 0.4[c]
Waist circumference change (cm)[2]	−2.3 ± 0.4[a]	−3.7 ± 0.4[b]	−5.7 ± 0.4[c]
BMI change (kg/m^2)[2]	0.9 ± 0.1[a]	1.4 ± 0.1[b]	2.1 ± 0.1[c]
Energy expenditure change (kcal · kg^{-1} · d^{-1})	0.2 ± 0.2	0.3 ± 0.2	0.7 ± 0.2
Energy density of food (kcal/g)			
Baseline	1.53 ± 0.03[a]	1.69 ± 0.03[b]	2.11 ± 0.03[c]
Change[2]	0.22 ± 0.02[a]	−0.31 ± 0.01[b]	−0.90 ± 0.02[c]
Total energy intake (kcal)			
Baseline	1833 ± 41[a]	1952 ± 40[b]	2117 ± 45[b]
Change[4]	11 ± 39[a]	−278 ± 32[b]	−511 ± 41[c]
Food energy intake (kcal)			
Baseline	1596 ± 36[a]	1720 ± 38[a,b]	1842 ± 42[b]
Change[4]	36 ± 36[a]	−244 ± 31[b]	−446 ± 39[c]
Beverage energy intake (kcal)			
Baseline	236 ± 12[a,b]	232 ± 10[a]	276 ± 14[b]
Change[2]	−25 ± 12	−34 ± 11	−65 ± 14
Food weight (g)			
Baseline	1089 ± 24[a]	1047 ± 22[a]	918 ± 22[b]
Change[2]	−91 ± 21[a]	73 ± 21[b]	297 ± 26[c]
Food groups (servings)			
Bread, cereals, rice, and pasta			
Baseline	4.66 ± 0.15	4.87 ± 0.16	5.15 ± 0.14
Change[4]	−0.07 ± 0.18[a]	−0.38 ± 0.16[a]	−1.04 ± 0.17[b]
Vegetables			
Baseline	3.24 ± 0.13[a]	2.95 ± 0.11[a]	2.26 ± 0.10[b]
Change[2]	−0.46 ± 0.12[a]	0.35 ± 0.13[b]	1.24 ± 0.13[c]
Fruit			
Baseline	1.96 ± 0.10[a]	1.71 ± 0.09[a,b]	1.55 ± 0.11[b]
Change[4]	−0.15 ± 0.11[a]	0.97 ± 0.14[b]	1.84 ± 0.19[c]
Dairy			
Baseline	1.63 ± 0.08	1.63 ± 0.07	1.73 ± 0.10
Change	0.11 ± 0.11	0.18 ± 0.09	0.20 ± 0.12
Meat			
Baseline	2.31 ± 0.09	2.54 ± 0.09	2.62 ± 0.10
Change[4]	0.07 ± 0.11[a]	−0.46 ± 0.08[b]	−0.64 ± 0.10[b]
Nuts, beans, and soy			
Baseline	0.55 ± 0.05	0.54 ± 0.05	0.54 ± 0.06
Change	0.03 ± 0.09	−0.13 ± 0.06	−0.10 ± 0.07
Fat and oils			
Baseline	5.70 ± 0.27	6.00 ± 0.26	5.93 ± 0.22
Change[4]	−0.62 ± 0.30	−1.49 ± 0.27	−1.45 ± 0.32
Sweets			
Baseline	3.91 ± 0.17[a]	4.15 ± 0.20[a,b]	4.84 ± 0.22[b]
Change[4]	−0.34 ± 0.28[a]	−1.38 ± 0.20[b]	−2.12 ± 0.23[b]
Macronutrient intakes			
Protein (g)			
Baseline	72 ± 2	78 ± 2	77 ± 2
Change[4]	1 ± 2[a]	−6 ± 2[a,b]	−7 ± 2[b]
Carbohydrate (g)			
Baseline	240 ± 6	247 ± 5	258 ± 6
Change[4]	−9 ± 5	−15 ± 5	−24 ± 6
Fat (g)			
Baseline	65 ± 2[a]	73 ± 2[b]	86 ± 2[c]
Change[4]	4 ± 2[a]	−21 ± 2[b]	−41 ± 2[c]
Saturated fat (g)			
Baseline	22 ± 1[a]	24 ± 1[b]	28 ± 1[b]
Change[4]	1 ± 1[a]	−7 ± 1[b]	−14 ± 1[c]
Fiber (g)			
Baseline	18 ± 1[a]	17 ± 1[a,b]	16 ± 1[c]
Change[4]	−1 ± 1[a]	2 ± 1[b]	4 ± 1[c]
Moisture (g)			
Baseline	1742 ± 43	1618 ± 33	1633 ± 39
Change[5]	−158 ± 43[a]	−23 ± 30[b]	156 ± 31[c]

(Continued)

TABLE 3 (*Continued*)

	6-mo change in dietary energy density		
	Tertile 1 (increase or small decrease) (n = 219)	Tertile 2 (medium decrease) (n = 220)	Tertile 3 (large decrease) (n = 219)
Micronutrient intakes			
Vitamin A (RE)			
Baseline	1212 ± 64[a]	1080 ± 49[a,b]	936 ± 54[b]
Change[2]	−205 ± 73[a]	219 ± 83[b]	383 ± 77[b]
Vitamin B-6 (mg)			
Baseline	1.8 ± 0.1	1.8 ± 0.1	1.7 ± 0.1
Change[4]	0.1 ± 0.1[a]	0.2 ± 0.1[b]	0.4 ± 0.1[b]
Vitamin B-12 (μg)			
Baseline	4.7 ± 0.3	4.6 ± 0.4	4.2 ± 0.3
Change[4]	0.2 ± 0.6	−0.1 ± 0.5	0.6 ± 0.5
Folate (μg)			
Baseline	356 ± 11	342 ± 9	339 ± 12
Change[4]	5 ± 11	37 ± 11	44 ± 13
Vitamin C (mg)			
Baseline	114 ± 5[a]	103 ± 4[a,b]	88 ± 4[b]
Change[4]	−12 ± 5[a]	18 ± 6[b]	68 ± 7[c]
Vitamin D (μg)			
Baseline	4.6 ± 0.2	4.8 ± 0.2	4.5 ± 0.2
Change	−0.5 ± 0.3[a]	0.3 ± 0.3[b]	0.3 ± 0.3[a,b]
Calcium (mg)			
Baseline	724 ± 23	749 ± 22	728 ± 24
Change[3]	8 ± 26	13 ± 26	75 ± 31
Sodium (mg)			
Baseline	3066 ± 83	3169 ± 85	3293 ± 86
Change[2]	−311 ± 91[a]	−719 ± 81[b]	−1045 ± 87[c]
Potassium (mg)			
Baseline	2681 ± 68	2631 ± 56	2481 ± 63
Change[4]	−112 ± 61[a]	218 ± 63[b]	564 ± 69[c]
Blood pressure			
Systolic (mm Hg)			
Baseline	135 ± 1	135 ± 1	134 ± 1
Change[2]	−9 ± 1[a]	−10 ± 1[a,b]	−11 ± 1[b]
Diastolic (mm Hg)			
Baseline	85 ± 1	85 ± 1	84 ± 1
Change[2]	−5 ± 1	−5 ± 1	−6 ± 1

[1] All values are $\bar{x}$ ± SE. The changes were 1.09 to −0.10, −0.11 to −0.51, and −0.52 to −2.35 kcal/g for increase or small decrease, medium decrease, and large decrease, respectively. Values in the same row with different superscript letters are significantly different, $P < 0.05$ (ANOVA using a general linear model adjustment for baseline values followed by a Tukey-Kramer adjustment for multiple comparisons). Paired *t* tests were used to determine whether change values differed from zero change.

[2] For each tertile, the change value is significantly different from zero change.

[3] For tertile 3, the change value is significantly different from zero change.

[4] For tertiles 2 and 3, the change value is significantly different from zero change.

[5] For tertiles 1 and 3, the change value is significantly different from zero change.

in dietary energy density had the largest reductions in EI and body weight. Nevertheless, these participants reported the largest increases in the weight of food they consumed and in their intakes of fiber and several vitamins and minerals.

This trial, which provided longitudinal dietary and anthropometric data on >600 persons, included several different treatment modalities. The 3 treatment groups received different amounts or types of dietary advice. Whereas the advice group was not provided with specific goals, the established and the established+DASH groups were provided with similar goals for energy restriction and weight loss. These 2 groups had comparable declines in EI and body weight. However, the strategies used to reduce EI differed. The established group was instructed to reduce portion sizes and dietary fat, whereas the established+DASH group was instructed to achieve a larger reduction in fat intake and to increase the consumption of fruit, vegetables, and low-fat dairy products. Consequently, the established+DASH group had a larger decline in energy density than did the established group. Because these 2 groups had similar declines in EI, this larger decline in energy density was associated with an increase in reported food consumption by the established+DASH group. These data indicate that the DASH diet, an eating plan that has been recognized as being consistent with the 2005 Dietary Guidelines (1), is a lower-energy-density eating plan. It can allow persons to consume less energy without necessarily reducing the total weight of food they eat, which may promote diet satisfaction and long-term compliance.

Because changes in energy density were experienced by participants in each treatment group, analyses were conducted by stratifying subjects by change in energy density values. Findings are in accordance with several cross-sectional studies that found relations between energy density and weight status (11–14).

TABLE 4
Stepwise regression models predicting changes in energy density and body weight among PREMIER trial participants ($n = 658$)[1]

Model and predictive variables	β Coefficient (SE)	Partial R^2	Model R^2	P
Model 1a[2]				
Fat intake change (g)	0.01 (0.01)	0.3385	0.3385	0.0001
Vegetable intake change (servings)	−0.06 (0.01)	0.1334	0.4719	0.0001
Fruit intake change (servings)	−0.03 (0.01)	0.0556	0.5275	0.0001
Protein intake change (g)	−0.01 (0.01)	0.0244	0.5518	0.0001
Moisture intake change (g)	−0.01 (0.01)	0.0139	0.5657	0.0001
Sweets (servings)	0.01 (0.01)	0.0105	0.5751	0.0001
Fats and oils intake change (servings)	0.02 (0.01)	0.0090	0.5861	0.0002
Fiber intake change (g)	−0.01 (0.01)	0.0049	0.5900	0.0056
Carbohydrate intake change (g)	0.01 (0.01)	0.0044	0.5944	0.0080
Dairy intake change (servings)	−0.03 (0.01)	0.0068	0.6012	0.0010
Model 1b[3]				
Baseline energy density	−0.43 (0.03)	0.3708	0.3708	0.0001
Fat intake change (g)	0.01 (0.01)	0.1518	0.5226	0.0001
Vegetable intake change (servings)	−0.05 (0.01)	0.0880	0.6106	0.0001
Fruit intake change (servings)	−0.04 (0.01)	0.0533	0.6638	0.0001
Protein intake change (g)	−0.01 (0.01)	0.0154	0.6792	0.0001
Moisture intake change (g)	−0.01 (0.01)	0.0096	0.6888	0.0001
Fiber intake change (g)	−0.01 (0.01)	0.0045	0.6933	0.0021
Carbohydrate intake change (g)	0.01 (0.01)	0.0066	0.6999	0.0002
Dairy intake change (servings)	−0.03 (0.01)	0.0063	0.7062	0.0002
Fats and oils intake change(servings)	0.01(0.01)	0.0057	0.7119	0.0004
Model 2a[4]				
Energy density change (kcal/g)	2.33 (1.5)	0.0747	0.0747	0.0001
Fiber intake change (g)	−0.21 (0.07)	0.0255	0.1001	0.0001
Fat intake change (g)	0.11 (0.02)	0.0320	0.1321	0.0001
Weight of food change (g)	−0.01 (0.01)	0.0149	0.1470	0.0009
Bread, cereals, rice, and pasta intake change (servings)	0.45 (0.18)	0.0090	0.1560	0.0094
Energy expenditure change (kcal · kg^{-1} · d^{-1})	−0.30 (0.15)	0.0050	0.1609	0.05
Model 2b[5]				
Energy density change (kcal/g)	2.19 (1.5)	0.0747	0.0747	0.0001
Fiber intake change (g)	−0.22 (0.07)	0.0255	0.1001	0.0001
Fat intake change (g)	0.11 (0.02)	0.0320	0.1321	0.0001
Weight of food change (g)	−0.01 (0.01)	0.0149	0.1470	0.0009
Bread, cereals, rice, and pasta intake change (servings)	0.43 (0.18)	0.0090	0.1560	0.0094
Baseline body weight (kg)	−0.02 (0.01)	0.0070	0.1629	0.02
Energy expenditure change (kcal · kg^{-1} · d^{-1})	−0.29 (0.15)	0.0049	0.1678	0.05

[1] Model 1 (a and b), predicting energy density change; Model 2 (a and b), predicting body weight change. A forward selection technique was used in which variables were allowed to enter the models at $P = 0.1$ and were allowed to stay in the model at $P = 0.05$.

[2] Included changes in macronutrient, moisture, and food group intakes.

[3] Included baseline dietary energy density and changes in macronutrient, moisture, and food group intakes.

[4] Included changes in energy, macronutrient, moisture, and food group intakes; food weight; energy density; and physical activity.

[5] Included baseline body weight and changes in energy, macronutrient, moisture, and food group intakes; food weight; energy density; and physical activity.

Conversely, several other cross-sectional studies failed to find relations between energy density and weight status (9, 10, 27). The failure to find significant relations between energy density and body weight may have been due to the cross-sectional nature of the studies if participants did not have a stable body weight. Several prospective studies, which did not specifically assess the energy density of the diet, found that diets emphasizing lower-energy-density foods, such as fruit, vegetables, and other low-fat foods, were associated with weight loss (28–30). One longitudinal study investigating energy density failed to find an association between dietary energy density and body weight; however, that study did not assess changes in energy density but instead compared baseline energy density values with 5-y weight changes (31). Three longitudinal studies showed that the energy density of the diet was related to weight loss (15, 16, 32). Rolls et al (15) found that the energy density of snacks provided to overweight and obese participants for incorporation into a reduced-energy diet affected weight loss over a year. Another yearlong study found that incorporating fruit and vegetables into a reduced-fat diet led to greater reductions in energy density and weight loss than did following a reduced-fat diet (16). These studies, as well as the present study, found changes in energy density to be the strongest predictor of weight loss, which provided support for the use of diets that are rich in lower-energy-density foods for weight management.

When the data from this trial were analyzed by the degree of change in energy density, a clear pattern emerged. The participants with the greatest reduction in the energy density of their diet had the greatest decrease in EI and the greatest reduction in body weight. When the data were analyzed by treatment group, the group with the greatest decline in energy density—the established+Dash group—did not lose a greater amount of weight than did the established group. There was no difference in the degree to which these 2 groups reduced their EI. Reducing dietary energy density is only one of many strategies that can be used to moderate EI.

Several other benefits other than weight loss are, however, associated with the consumption of a diet that is lower in energy density. This type of eating plan, which emphasizes the types of foods to be integrated into the diet as opposed to emphasizing those that should be restricted, provides a positive approach to weight management. Weight-management strategies typically used to reduce EI focus on limitations in portion sizes, food groups, or certain macronutrients. Such restrictive approaches can lead to short-term weight loss (33, 34), but they may cause feelings of hunger or dissatisfaction, which can limit their acceptability, sustainability, and long-term effectiveness (35–37). Whereas measures of hunger or diet satisfaction were not assessed as part of the present study, participants with medium and large decreases in dietary energy density (tertiles 2 and 3) did increase the weight of food they consumed; that may have helped to control feelings of hunger and to promote feelings of satiety while reducing energy intakes. Multiple laboratory-based studies showed that hunger and satiety are not adversely influenced by reductions in EI when those reductions are achieved by lowering the energy density of the meals (2–4, 7, 8, 17).

An additional benefit of adopting a diet that is low in energy density is improved diet quality. A previous cross-sectional study with a population-based sample of US adults found that diets that were lower in energy density were associated with a high diet quality (20). The present study provides further evidence that diets that are low in energy density are nutritionally sound. Participants who decreased the energy density of their diet reported increased intake of fiber and several vitamins and minerals. The adoption of a lower-energy-density diet was also associated with an increase in reported fruit and vegetable consumption. Whereas a decrease in body weight is a primary goal of a weight-loss diet, consideration of nutritional quality is equally important.

Before these analyses, information was not available regarding the magnitude of changes in dietary energy density that could be achieved during dietary interventions. One-third of the participants in this study reduced the energy density of their diet by ≥0.52 kcal/g. Because baseline BMI and waist circumference values were higher in these participants than in all others, these participants may have been more motivated to lose weight and therefore were more compliant with the dietary protocol. In addition, because these participants had the highest baseline energy density values, they had the greatest opportunity to make changes to their diet. Whereas the most substantial change in energy density was associated with the largest decrease in body weight, it is important to note that there were beneficial effects associated with more modest changes in energy density. Participants who reduced the energy density of their diet by 0.11–0.51 kcal/g also experienced significant declines in EI and body weight, while increasing the weight of food they consumed. In the present study, participants consumed ≈1000 g food/d at baseline, which is similar to findings from population-based data (25). Therefore, a reduction in dietary energy density of 0.20 kcal/g would translate into a reduction of ≈200 kcal/d if a person continued to consume the same weight of food. Further research is needed, but these more modest reductions in energy density, which require less deviation from one's typical eating pattern, may be effective for long-term weight management.

Baseline energy density values for participants in the present study were comparable with nationally representative values (25). Intensive study recruitment and screening procedures may have led to the selection of a group of individuals who were highly motivated to lose weight. Even the advice group experienced a mean decline in body weight. The differences in weight loss among the 3 groups may have partially resulted from differences in contact time, because the advice group received a single counseling session, whereas the established and established+DASH groups had 18 intervention contacts. Another limitation of these analyses is that, because of the nature of the study, dietary energy density was based on self-reported food intakes. The inaccurate reporting that probably occurred is likely to have weakened associations with weight status. The data, however, were collected by a 24-h recall with multiple passes and portion size estimation aids to improve the accuracy of the data. Only 2 d of dietary intake data were available at each time point; however, the changes in nutrient profiles were consistent with what would be expected on the basis of the prescribed dietary interventions and with anthropometric changes. It is also likely that conducting analyses in which all of the participants were pooled decreased demand- bias created by the different dietary advice to reduce EI that the participant groups received. Whereas participants with the largest decrease in the energy density of their diet had the highest baseline energy density values, as well as the lowest fruit and vegetable intakes, baseline values were included in the models as covariates to adjust for these differences.

In summary, achievement of considerable weight loss was related to reductions in the energy density of the diet. Participants with diet patterns characterized by the largest decrease in the energy density had the greatest decrease in EIs and the largest declines in body weight. Even modest reductions in energy density that accompanied increased intakes of fruit, vegetables, fiber, vitamins, and minerals and of the total weight of food consumed were associated with reduced body weight. These data indicate that a reduction in dietary energy density (even a modest reduction) is a healthy weight-management strategy. Eating patterns that are low in energy density, such as the DASH diet, can help to improve the efficacy of dietary interventions in the prevention and treatment of obesity.

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REFERENCES

1. Dietary guidelines for Americans 2005. 6th ed. Washington, DC: US Department of Health and Human Services, US Department of Agriculture, 2005.
2. Bell EA, Castellanos VH, Pelkman CL, Thorwart ML, Rolls BJ. Energy density of foods affects energy intake in normal-weight women. Am J Clin Nutr 1998;67:412–20.
3. Rolls BJ, Bell EA, Castellanos VH, Chow M, Pelkman CL, Thorwart ML. Energy density but not fat content of foods affected energy intake in lean and obese women. Am J Clin Nutr 1999;69:863–71.
4. Bell EA, Rolls BJ. Energy density of foods affects energy intake across multiple levels of fat content in lean and obese women. Am J Clin Nutr 2001;73:1010–8.

5. Devitt AA, Mattes RD. Effects of food unit size and energy density on intake in humans. Appetite 2004;42:213–20.
6. Stubbs RJ, Whybrow S. Energy density, diet composition and palatability: influences on overall food energy intake in humans. Physiol Behav 2004;81:755–64.
7. Rolls BJ, Roe LS, Meengs JS. Salad and satiety: energy density and portion size of a first-course salad affect energy intake at lunch. J Am Diet Assoc 2004;104:1570–6.
8. Rolls BJ, Roe LS, Meengs JS. Reductions in portion size and energy density of foods are additive and lead to sustained decreases in energy intake. Am J Clin Nutr 2006;83:11–7.
9. Cuco G, Arija V, Marti-Henneberg C, Fernandez-Ballart J. Food and nutritional profile of high energy density consumers in an adult Mediterranean population. Eur J Clin Nutr 2001;55:192–9.
10. de Castro JM. Dietary energy density is associated with increased intake in free-living humans. J Nutr 2004;134:335–41.
11. Stookey JD. Energy density, energy intake and weight status in a large free-living sample of Chinese adults: exploring the underlying roles of fat, protein, carbohydrate, fiber and water intakes. Eur J Clin Nutr 2001; 55:349–59.
12. Kant AK, Graubard BI. Energy density of diets reported by American adults: association with food group intake, nutrient intake, and body weight. Int J Obes (Lond) 2005;29:950–6.
13. Marti-Henneberg C, Capdevila F, Arija V, et al. Energy density of the diet, food volume and energy intake by age and sex in a healthy population. Eur J Clin Nutr 1999;53:421–8.
14. Ledikwe JH, Blanck HM, Kettel Khan L, et al. Dietary energy density is associated with energy intake and weight status in US adults. Am J Clin Nutr 2006;83:1362–8.
15. Rolls BJ, Roe LS, Beach AM, Kris-Etherton PM. Provision of foods differing in energy density affects long-term weight loss. Obes Res 2005;13:1052–60.
16. Ello-Martin JA, Roe LS, Ledikwe JH, Beach AM, Rolls BJ. Dietary energy density in the treatment of obesity: a year-long trial comparing two weight-loss diets. Am J Clin Nutr (in press).
17. Rolls BJ, Drewnowski A, Ledikwe JH. Changing the energy density of the diet as a strategy for weight management. J Am Diet Assoc 2005; 105:98–103.
18. Karanja NM, Obarzanek E, Lin PH, et al. Descriptive characteristics of the dietary patterns used in the Dietary Approaches to Stop Hypertension Trial. DASH Collaborative Research Group. J Am Diet Assoc 1999;99: S19–27.
19. Hedley AA, Ogden CL, Johnson CL, Carroll MD, Curtin LR, Flegal KM. Prevalence of overweight and obesity among US children, adolescents, and adults, 1999–2002. JAMA 2004;291:2847–50.
20. Ledikwe JH, Blanck HM, Khan LK, et al. Low-energy-density diets are associated with high diet quality in adults in the United States. J Am Diet Assoc 2006;106:1172–80.
21. Svetkey LP, Harsha DW, Vollmer WM, et al. Premier: a clinical trial of comprehensive lifestyle modification for blood pressure control: rationale, design and baseline characteristics. Ann Epidemiol 2003;13:462–71.
22. Funk KL, Elmer PJ, Stevens VJ, et al. PREMIER—a trial of lifestyle interventions for blood pressure control: intervention design and rationale. Health Promot Pract 2006 Jun 27 (Epub ahead of print).
23. Appel LJ, Champagne CM, Harsha DW, et al. Effects of the comprehensive lifestyle modification on blood pressure control: main results of the PREMIER clinical trial. JAMA 2003;289:2083–93.
24. Chobanian AV, Bakris GL, Black HR, et al. The Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure: the JNC 7 report. JAMA 2003;289: 2560–72.
25. Ledikwe JH, Blanck HM, Kettel-Khan L, et al. Dietary energy density determined by eight calculation methods in a nationally representative United States population. J Nutr 2005;135:273–8.
26. Blair SN, Haskell WL, Ho P, et al. Assessment of habitual physical activity by a seven-day recall in a community survey and controlled experiments. Am J Epidemiol 1985;122:794–804.
27. Drewnowski A, Almiron-Roig E, Marmonier C, Lluch A. Dietary energy density and body weight: is there a relationship? Nutr Rev 2004; 62:403–13.
28. Fitzwater SL, Weinsier RL, Wooldridge NH, Birch R, Liu C, Bartolucci AA. Evaluation of long-term weight changes after a multidisciplinary weight control program. J Am Diet Assoc 1991;91:421–6, 429.
29. Epstein LH, Gordy CC, Raynor HA, Beddome M, Kilanowski CK, Paluch R. Increasing fruit and vegetable intake and decreasing fat and sugar intake in families at risk for childhood obesity. Obes Res 2001;9: 171–8.
30. Stamler J, Dolecek TA. Relation of food and nutrient intakes to body mass in the special intervention and usual care groups in the Multiple Risk Factor Intervention Trial. Am J Clin Nutr 1997;65(suppl):366S–73S.
31. Iqbal SI, Helge JW, Heitmann BL. Do energy density and dietary fiber influence subsequent 5-year weight changes in adult men and women? Obes Res 2006;14:106–14.
32. Greene LF, Malpede CZ, Henson CS, Hubbert KA, Heimburger DC, Ard JD. Weight maintenance 2 years after participation in a weight loss program promoting low-energy density foods. Obesity (Silver Spring) 2006;14:1795–801.
33. Dansinger ML, Gleason JA, Griffith JL, Selker HP, Schaefer EJ. Comparison of the Atkins, Ornish, Weight Watchers, and Zone diets for weight loss and heart disease risk reduction: a randomized trial. JAMA 2005;293:43–53.
34. Foster GD, Wadden TA, Peterson FJ, Letizia KA, Bartlett SJ, Conill AM. A controlled comparison of three very-low-calorie diets: effects on weight, body composition, and symptoms. Am J Clin Nutr 1992;55: 811–7.
35. Cuntz U, Leibbrand R, Ehrig C, Shaw R, Fichter MM. Predictors of post-treatment weight reduction after in-patient behavioral therapy. Int J Obes Relat Metab Disord 2001;25(suppl):S99–101.
36. Pasman WJ, Saris WH, Westerterp-Plantenga MS. Predictors of weight maintenance. Obes Res 1999;7:43–50.
37. Elfhag K, Rossner S. Who succeeds in maintaining weight loss? A conceptual review of factors associated with weight loss maintenance and weight regain. Obes Rev 2005;6:67–85.